Progress Report

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Extended Validation of AMSR-E Soil Moisture Products

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Project Objectives

The aim of this proposal is to enhance, complement and supplement the activities of the AMSR-E science team to characterize and validate the accuracy of soil moisture derived from the AMSR-E data. The project includes a broad spectrum of validation activities that will ensure an integrated validation plan. The research objectives of the current project are:

a. Validation of AMSR soil moisture retrievals for time periods on the order of days to months to years using in-situ observations within USDA-ARS research watersheds. These watersheds represent a range of physiographic and climatologic conditions in the continental U.S.
b. Provide an assessment of the AMSR-E brightness temperature over land through comparisons with TMI observations over land.
c. Provide the scientific community and public with all data and results of the investigation.

Progress to Date

The original proposal had three elements: insitu validation of soil moisture, algorithm intercomparison, and cal/val of brightness temperature over land using other satellite sensors. This was expanded to include support for large-scale field experiment (Soil Moisture Experiments-SMEX) data collection and processing, which now represents a major portion of our efforts.

Insitu Validation of the Soil Moisture Products

The sampling and analyses that we designed extends and strengthens other validation activities including intensive field observation, operational networks, and model based validation of AMSR products.

Existing instrumentation in and surrounding ARS research watersheds located in Oklahoma, Georgia, Arizona, and Idaho has been augmented to include surface soil moisture and temperature observations. The locations of these watersheds are shown in Figure 1. These include a wide range of climate zones, which should enhance the robustness of the validation of the AMSR-E soil moisture algorithm. Each watershed was previously instrumented with a USDA NRCS Soil Climate Analysis Network (SCAN) station and its own unique meteorological networks.

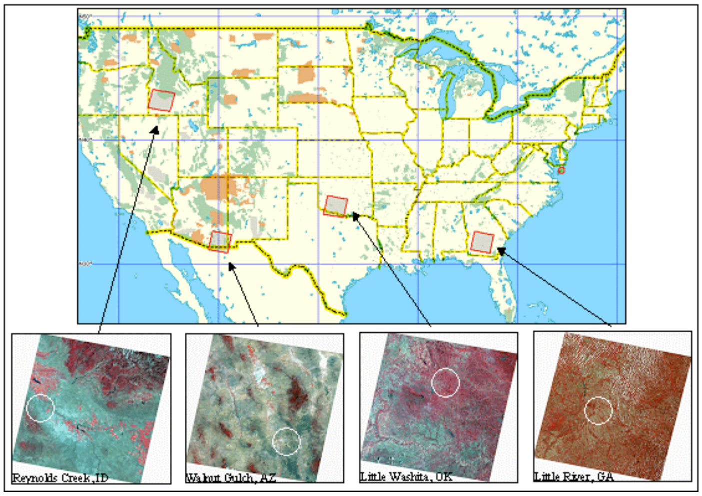

Figure 1. Locations of the ARS watersheds. The watershed locations are shown on the Landsat Thematic Mapper false color composite images as circles.

Surface soil moisture and temperature sensors (0-5 cm) (Vitel Hydraprobe) were installed at existing instrument locations in the watersheds (~20/watershed). This approach takes advantage of the available data logging and transmission equipment and provides important complementary meteorological information needed for a thorough hydrologic analysis. Each watershed location utilizes a slightly different approach to data collection. Part of this project is the merger of these datasets into a common format and the transfer to the NSIDC DAAC.

All of the originally planned instrumentation has been installed at this point. Some ongoing maintenance has been required, as we have begun the process of calibration and verification of sensor performance. It is the nature of soil moisture sensors that installation problems can show up sometime after installation as soils settle or shift. Each location is considering adding a few additional points outside the watershed to strengthen the spatial domain, if additional resources are available in the future. Figure 2 illustrates the basic components of the network using the Little Washita Watershed, OK.

Investigators from each of the watershed locations have initiated site-specific calibration and validation of the soil moisture networks. There are three extremely important issues that we have begun to investigate that will have wide ranging importance to validation of soil moisture products. These are the calibration and performance verification of the network sites, temporal stability analysis to define regional behavior, and linking the network averages to even larger domains.

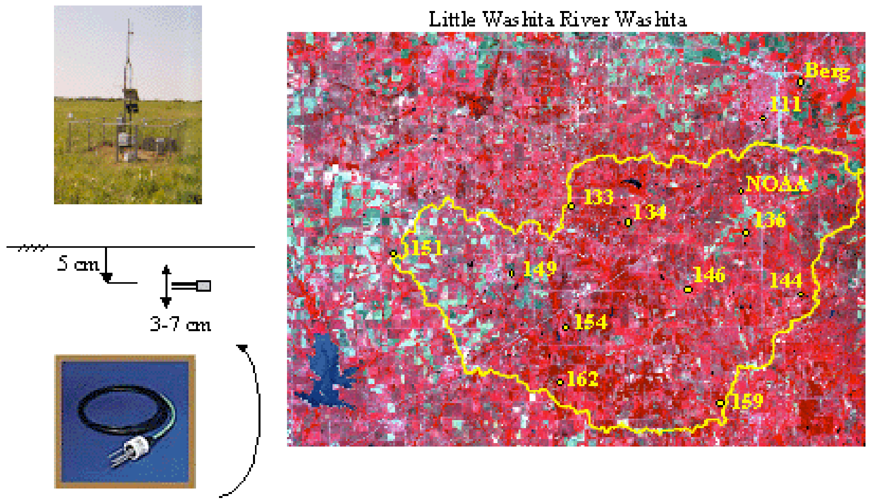

Figure 2. The Little Washita, OK Vitel soil moisture network.

As noted above, although the Vitel Hydraprobe is one of the most reliable and robust insitu soil moisture sensors available, the specific soil conditions at a site must be considered. In addition, because theses sensors must be installed using an excavated pit there is always the possibility of installation problems that show up after soils have settled. Therefore, investigators have been conducting independent gravimetric based sampling at these sites to check the factory supplied calibration equations. It is our intention, to develop site-specific calibrations and to reprocess all insitu observations. These sampling tests have been performed either to capture a range of conditions or as part of a SMEX campaign.

Another approach to network calibration is to use the averages of the network and averages obtained by conventional sampling. Figure 3 shows the results of such a comparison in the Little Washita Watershed, OK. The comparison was conducted during the SMEX03 campaign. Although the soil moisture conditions were relatively dry, the results clearly show a close correspondence between the network and the gravimetric sampling. From these results were can conclude that the Vitel network is accurately estimating the average soil moisture. This gives us some degree of confidence in using the network outside of the field campaign period to valid footprint soil moisture from AMSR-E. In addition, similar results have been obtained in Georgia.

A major focus of our efforts in this area has been conducting temporal stability analysis of the networks. Temporal stability can be used to assess how well any point in a population represents the average. For a specific site, the value of soil moisture for a day is compared to the average of all sites (without that site) to compute the relative difference. This is performed for all dates and a Mean Relative Difference for that site is determined.

$$\bar{\ddot{a}}_i = \frac{1}{t}\sum_{j=1}^{t}\frac{S_{i,j} - \bar{S}_j}{\bar{S}_j}$$

Where Si,j is the jth sample at the ith site of n sites. A “good” site has a zero mean relative difference and small standard deviation of that mean relative difference. Analyses can indicate the best sites and the worst sites.

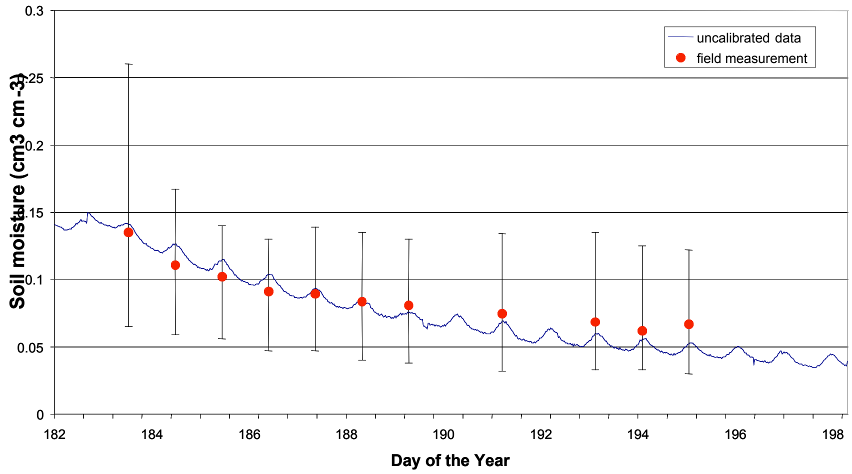

Figure 3. Little Washita Watershed, OK average soil moisture during SMEX03 comparison of Vitel network and gravimetric sampling.

As an example of a temporal stability analysis, the data from the Little Washita Watershed for several months were analyzed. Figure 4 summarizes the results. From this figure we can identify the “best” sites for representing the watershed average are 162, 146, and 149. The very important conclusion from this analysis is that we could estimate the average with good accuracy using a single point, if we could determine this apriori. Developing a method to do this will require more research and more robust conditions. However, if there existed a readily determined feature that could be used to identify such point we could develop very efficient monitoring network for characterizing large footprint satellite estimates of soil moisture. ”Good” sites have a mean relative close to zero and a small standard deviation.

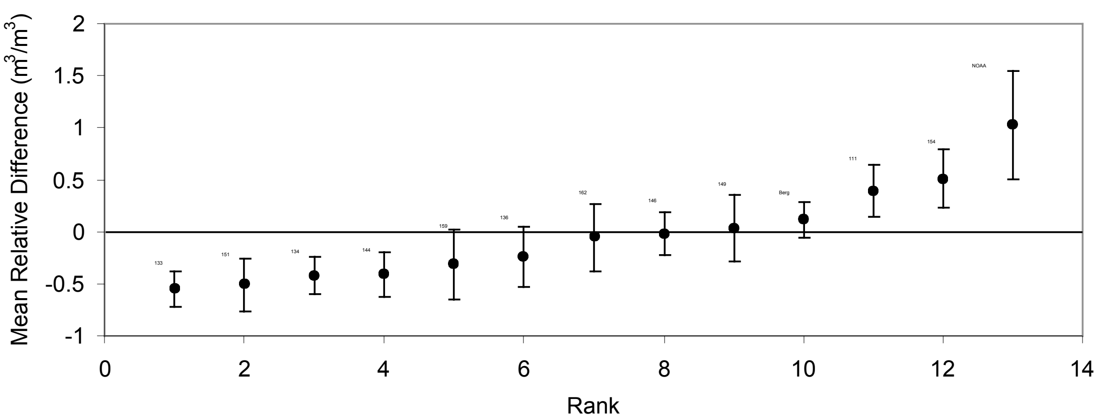

Figure 4. Temporal stability analysis of the Little Washita Watershed, OK Vitel network.

Algorithm Intercomparison

Three types of data are the focus of this component of the project; SMMR, TMI, and AMSR-E/AMSR. The AMSR instrument has similar channels to the Scanning Multichannel Microwave Imager (SMMR). Even though, during the tenure of SMMR (1987-1988), there were no field campaigns for in-situ observations, the C-band (6.6 GHz) channel did not suffer from the problems of Radio Frequency Interference (RFI). The data from SMMR forms a valuable long-term data set to study the properties of microwave observations of the land surface. The 6.6, 10.7 and 18 GHz data from SMMR for 1979, 1980 and 1982 have been used to derive soil moisture and surface temperature for the south central United States. The 1979 data has been used to calibrate the radiative transfer model parameters and the 1980 and 1982 were used to derive soil moisture and surface temperature that have been compared with the corresponding values from the National Centers for Environmental Prediction (NCEP) re-analyses model outputs. These comparisons have shown that SMMR is able to qualitatively predict the seasonal cycle of land surface hydrological variability and this information can be used for studies involving land-atmosphere interaction and hydrology. The results of this study will help us to plan for AMSR retrievals of soil moisture and surface temperature.

Regarding our TMI studies, as the AMSR has the X-band channel of 10.65 GHz that is not contaminated by RFI, an interesting inter-comparison is the 10.65 GHz channel of TMI that has a long data observation period (5 years: 1998-present). The properties from the long term observation using the X-band of TMI will help us fine-tune the utilization of the 10 GHz channel of AMSR in conjunction with the RFI contaminated C-band of AMSR. One approach to these requirements is to collect and compare long-term in-situ (field) measurements of soil moisture with remotely sensed data. In-situ measurements were collected at the Little River Watershed and compared to the Tropical TMI 10.65 GHz V and H sensors. It was found that the TMI was able to observe soil moisture conditions when vegetation levels were low. However, during several months each year high vegetation levels mask the soil moisture signal from the TMI. When the observation from the TMI, MODIS, and in-situ probes were subjected to a multivariable comparison the correlation value increased slightly, improving the accuracy of the TMI SOIL – soil moisture correlation. After the satellites are adequately calibrated over sampling regions soil moisture conditions over vast areas can be readily obtained.

The third area of research in this portion of the project involves the direct simulation of AMSR, AMSR-E brightness temperatures, retrieval of soil moisture and comparison of derived products with observations from field experiments. The simulated brightness temperatures show a greater range from dry days to wet days, after the rain event. A mean decrease in AMSR brightness temperature of 18 K was observed for the 10.65 GHz horizontally and vertically polarized channels, respectively. A mean decrease in estimated brightness temperature of 26 K and 25 K was observed for the 10.65 GHz horizontally and vertically-polarized channels, respectively. The polarization difference TB illustrates the greater change in estimated brightness temperatures than observed from before the rainfall to after (Figure 5). The greater range in estimated brightness temperatures than observed AMSR brightness temperatures could be a result of sub-footprint heterogeneity. Data from the 47 field sites are used to calculate brightness temperature throughout the region. The heterogeneity of the rainfall event and land cover from field to field results in greater variation in ground conditions than the few AMSR footprints that fall entirely within the region. For this reason, the estimated values show more range and are typically lower than the observed. Similar results were observed in the other frequencies, with the 6.9 GHz

AMSR channel showing a greater response to soil moisture changes. However, the 6.9 GHz channel was prone to large amounts of radio frequency interference in and around Des Moines, IA, and other regions within the study area. Therefore, this work has focused on the more stable 10.65 GHz channel.

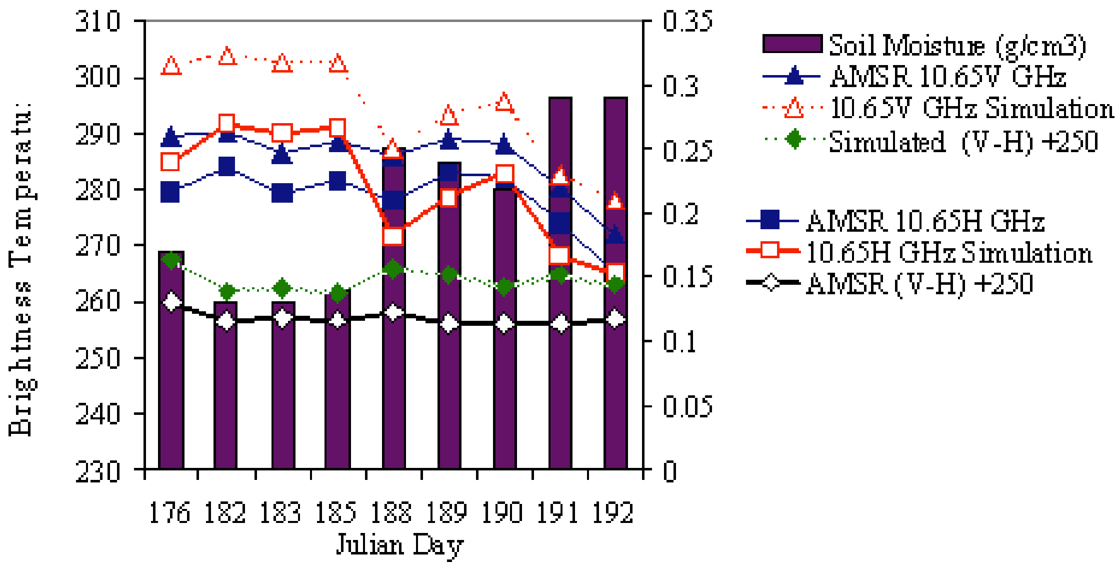

Figure 5. Mean soil moisture and brightness temperatures for all common days during SMEX02.

Large Scale Aircraft Experiments

During the past year we planned, implemented and successfully conducted the SMEX03 field campaign. SMEX03 was the second in aeries of three campaigns designed to provide validation data for the AMSR-E soil moisture products in a diverse set of climate and vegetation regimes. SMEX03 incorporated ground and aircraft observations at four sites; Alabama, Oklahoma, Georgia, and Brazil.

Intensive soil moisture sampling and aircraft mapping with the Polarimetric Scanning Radiometer (PSR C/X) was conducted between June 25th and July 12th over the sites in the U.S. Additional aircraft based mapping was also performed during this period with 2DSTAR and AIRSAR. Data from theses aircraft instruments is being processed and it is expected that this will be completed by July 2004.

Data Management

There are two separate data management activities under this project, each involving numerous contributors. The first component involves the soil moisture network data. Data quality and preprocessing are performed at the location level. These data will then be assembled for all locations at the NSIDC DAAC. Our goal is to eventually update these records on a monthly basis.

The second component involves the SMEX data sets. These are large and diverse data sets that originate from a wide variety of sources and contributors. We are following the model that we successfully used in SGP97 and SGP99. This involves working closely with both our contributors and the DAAC. We promote timeliness by holding workshops and telecons to keep people aware and focused. Nearly all SMEX02 data sets have been delivered to the NSISC DAAC. We anticipate that 50% of the data sets from SMEX03 will be delivered to the DAAC by the end of July 2004.

Plans

Our tasks for this project are listed below. Two important items for the coming year are the planning and implementation of the SMEX04 experiment and completing the flow of data from the watershed networks to an accessible archive. Both of these are challenging tasks.

Insitu Validation

- Calibration of existing real-time observation stations within ARS watersheds
- Examination of the averaging and variability and temporal persistence for soil moisture in each watershed
- Provide real time observations at a point and average values within 30 days as well as ancillary meteorological observations

Satellite Data Comparison

- Compare the 19 GHz and 37 GHz channels of all satellites – AMSR, TMI, SSM/I
- Compare 10 GHz for TMI, MSMR, and AMSR-E
- Compare AMSR-E and AMSR when available

Large Scale Aircraft Experiments

- Provide processed 6.9 GHz and 10 GHz aircraft data to the AMSR science team from the SMEX02, SMEX03 and SMEX04 experiments.
- Provide regional ground validation for validation of soil moisture from aircraft microwave observation in SMEX04.

Accomplishments

Peer Reviewed Publications

- Cosh, M.H., J. Stedinger, and W. Brutsaert, Time changes in spatial structure of surface variability in the Southern Great Plains, *Advances in Water Resources*, 26:407-415. 2003.
- Cosh, M.H., T.J. Jackson, R. Bindlish, and J. Prueger, Watershed scale temporal persistence of soil moisture and its role in validating satellite estimates, *Remote Sensing of Environment*, in press.
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- Guha, A. and V. Lakshmi, Retrieval of land surface parameters using passive microwave remote sensing, *IEEE Transactions on Geoscience and Remote Sensing*, in press
- Jackson, T.J., D. Chen, M.H. Cosh, F. Li, C. Walthall, M. Anderson, and P. Doraiswamy, Vegetation water content mapping using Landsat TM derived NDWI for corn and soybeans, *Remote Sensing of Env.*, in press.
- Kustas, W.P., T.J. Jackson, J.H. Prueger, M.C. Anderson, Remote sensing field experiments for evaluating soil moisture retrieval algorithms and modeling land-atmosphere dynamics in central Iowa, *EOS Trans. American Geophysical Union*, 84:485-493, 2003.
- Li, F., Jackson, T.J., Kustas, W. P., Schmugge, T. J., French, A., Cosh, M. H., and Bindlish, R., Deriving land surface temperature from Landsat 5 and 7 during SMEX02/SMACEX, *Remote Sensing of Env.*, in press.
- Njoku, E., T.J. Jackson, V. Lakshmi, T. Chan, S. Nghiem, Soil moisture retrieval from AMSR-E, *IEEE Transactions on Geoscience and Remote Sensing,* 4:215-229. 2003

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Other Publications

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- Cosh, M.H., T.J. Jackson, R. Bindlish, and J.H. Prueger, Estimation of watershed scale soil moisture from point measurements during SMEX02, in: Renard, Kenneth G., McElroy, Stephen A., Gburek, William J., Canfield, H. Evan and Scott, Russell L., eds. 2003. First Interagency Conference on Research in the Watersheds, October 27-30, 2003. U.S. Department of Agriculture, Agricultural Research Service, 205-211. 2003.
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- Kennedy, J., T. Keefer, G. Paige, F. Bårnes, Evaluation of dielectric constant - based soil moisture sensors in a semiarid rangeland, in: renard, Kenneth G., McElroy, Stephen A., Gburek, William J., Canfield, H. Evan and Scott, Russell L., eds. 2003. First Interagency Conference on Research in the Watersheds, October 27-30, 2003. U.S. Department of Agriculture, Agricultural Research Service, 503-508. 2003.
- Lakshmi, V., Cashion, J., Bosch, D.D., Jackson, T.J., Remote sensing of soil moisture: calibration of the TMI satellite over Tifton, Georgia, Electromagnetic Wave Interaction with Water and Moist Substances Proceeding. pp. 335-341. 2003.
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- Grant, L.E., and M.S. Seyfried. Distribution of soil moisture dynamics in a small mountain catchment. Presented at Fall Meeting, AGU, 2003, San Francisco.
- Lakshmi, V., J. Bolten, U. Narayan, T. Jackson, Estimation of Soil Moisture Using Data from Advanced Microwave Scanning Radiometer, International Geoscience and Remote Sensing Symposium, Toulouse, France, July 22-29, 2003
- Bosch, D., V. Lakshmi, J. Jacobs, T. Jackson, Soil moisture observations for validation of remotely sensed data: SMEX 03, Georgia, American Geophysical Union Fall Meeting, December 8-12, 2003
- Cashion, J., V. Lakshmi, D. Bosch, Use of TRMM Microwave Imager (TMI) to characterize soil moisture for the Little River Watershed, American Geophysical Union Fall Meeting, December 8-12, 2003
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